THE GEOLOGY AND PETROGRAPHY OF THE CLARENCETOWN-PATERSON DISTRICT.*

Part iv. Petrography.

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(Plate xxiii.)

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Introduction.

The present paper completes the series on the Clarencetown-Paterson district. Former papers have dealt with a discussion of the stratigraphy, physiography and tectonic geology of the whole region, and also with a detailed study of the Main Glacial Beds at Seaham (Osborne, 1922, 1925). In the following pages a detailed petrographical account of the Kuttung Series is given, and some little mention is made of certain Cainozoic basic rocks which occur in small masses throughout the area. The rocks of the Burindi Series are not described, because the area of their outcrops is small and also because these outcrops are the southward continuations of large areas to the north, where important massive igneous rocks occur. It is hoped that an examination of these will be possible in the future.

The greater part of the material in the present paper is of a descriptive nature. The author feels that the time has not yet come when the broader problems of petrogenesis in connection with the Carboniferous igneous rocks can be solved, nor can much be done regarding the correlation of the Carboniferous areas to the north near Tamworth and Werris Creek with those of the Lower Hunter district. These things will only be possible after some examination has been made of the Carboniferous country between Singleton and Murrurundi—work which the writer hopes to pursue in the immediate future. Therefore in the following discussion a systematic account will be given of the rocks, taken in groups according to their identity, and some general remarks made upon certain interesting features exhibited by the rocks when considered as a whole.

It should be pointed out that in 1919 a short report on the petrology of some of the rocks from parts of the district now being considered, was made by W. R. Browne (Sussmilch and David, 1919, Appendix 2). This report, though brief, proved of considerable help to the writer in connection with his introduction to the problems of the Carboniferous igneous rocks. In fact the author wishes here to emphasize his indebtedness to Assistant-Professor Browne for his help and advice during the whole of his work on the petrology of the Carboniferous rocks of New South Wales. It must also be mentioned, that, as a result of his studies in the Gosforth-Eelah region, near Maitland, Dr. Browne has observed many facts about

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* About three-fourths of the work entailed in the preparation of this paper was carried out while the writer held the position of Demonstrator in Geology, University of Sydney.

the Kuttung petrology which have not yet been placed on record by him, but which have been arrived at independently by the present author in connection with his work in the Paterson-Dungog area.

In connection with the chemical investigation of the rocks, the writer is very grateful to Mr. H. P. White, F.C.S., through whose good offices an analysis was kindly performed by Mr. W. A. Greig.

Thanks are also due to Mr. G. W. Card and Mr. C. A. Sussmilch for the loan of certain slides of the Kuttung igneous rocks.

General Discussion of Certain Features of the Rocks.

Sequence of the lavas and correlation of various sections.

The igneous rocks of the Clarencetown-Paterson district comprise a wide variety, embracing representatives of the following types: andesites and andesitic pitchstones, dacites, toscanites, dellenites, quartz-keratophyres, rhyolites and felsites. Associated with these are tuffs and flow-breccias of rhyolitic and keratophyric composition.

The question of the order of extrusion of the lavas was briefly discussed in an earlier paper (1922) and it was pointed out that a general sequence, only, held throughout the area, but modifications were found in many localities, so that the order obtaining in one district was appreciably different from that occurring in another, and it was clear that only by extremely detailed field and chemical study would one be likely to solve the problems presented by the association of calcic and alkaline rocks. The difficulties involved in examining the facts of the sequence from a petrogenetic point of view are, in great measure, due to the presence of phenomena resulting from the albitization of some or all of the original felspathic content of certain rocks, whereby their magmatic relations with other rocks, and with each other, have become obscure.

However, there is present an order of extrusion in which the following are the salient features: rocks of intermediate composition—glassy and lithoidal mica-amphibole-andesites (*a*)—are the first flows to appear; these are followed by the pyroxene-andesites (*b*) which are of greater basicity, and then comes a series of quartz-keratophyres (*c*), dacites (*d*), toscanites and dellenites and rhyolites (*e*), all more acidic than group (*a*). In this series there is considerable variation in the order of the types. If, as Browne and Walkom have suggested (1911, p. 294) the basalts (*f*) of the Permian (some representatives of which occur near Seaham) belong to, and represent the last expression of, the magma which was so active in Kuttung times, then the sequence through Kuttung and Lower Permian time would appear in a general way to represent one which was characterized, to quote Harker, by "a divergence from the initial type." And as Harker (1909) has shown for certain volcanic districts in Nevada, Mexico, and Germany, there is, in the case of the rocks now being considered, increasing acidity in the order (*a*), (*c*), (*d*), (*e*) and increasing basicity in the order (*a*), (*b*), (*f*).

It must not be forgotten, however, that there are lavas in the Burindi Series, and these should really be considered in connection with any inquiry into the petrological evolution of the igneous rocks of the Upper Palaeozoic of New South Wales, but there seems to be evidence of a substantial time break between the Burindi extrusions and those of Kuttung times, and it is quite reasonable (at all events in the Paterson-Dungog district) to look upon the extrusion of the andesites which occur towards the base of the Kuttung, as being the beginning of a subsequent, but more or less distinct, period in the larger volcanic cycle, which began in Burindi time. In any case, the Burindi lavas, nearest stratigraphically to the Kuttung flows, are hornblende-andesites, almost identical with those described here.

With regard to the correlation of flows over the whole area, the reader is referred to the account of the Regional Geology of the district given in the first paper of this series. There details of the relationship between certain lavas in the western areas and those in the east are given, and it is pointed out that some of the flows are characterized by the fact that they change along the strike.

In his presidential address to the Royal Society of New South Wales (1923), Mr. C. A. Sussmilch attempted to correlate certain sections at Martin's Creek and Eelah with two which had been previously described by the writer (see Sussmilch, 1923, Plate I), but certain units were linked together, which are very different as regards both mineralogical and chemical composition, and also stratigraphical position. Thus, in the Glenoak section, a quartz-keratophyre was placed as being equivalent to the Mt. Gilmore type of toscanite, and a rock which, in the Martin's Creek section, has been referred to as a dacite, but has later been described by the present author as a keratophyre, was shown as the equivalent of certain rhyolites in the eastern areas. In both cases these correlations are incorrect, and indeed it is only by the closest scrutiny of the microscopical details and field evidence that any correlation can be made wisely. On account of the peculiar features of order of succession, which the rocks under review exhibit, the present writer has been able to correlate the dominant units only.

Evidence of the Operation of late-magmatic Processes.

Albitization.—Phenomena produced in igneous rocks as a result of the activity of cognate solutions and gases acting during the last stages of, or immediately after, the consolidation of the main masses, have frequently been the subject of investigation by petrographers. One of the most important of such processes is that of albitization, whereby particularly the basic plagioclase of a rock, and at times other constituents too, become replaced by albite. Bailey and Grabham (1909) described in some detail the changes of this nature in certain Upper Palaeozoic igneous rocks of Scotland, citing other instances where albitization appears to have occurred. Many spilitic rocks have evidently been developed as a result of albitization, and Benson (1918) mentioning how Neithammer (1908) has suggested and Bailey (1911) has confirmed that many keratophyres are albitized porphyrites, summarized his own views generally that albitization by late-magmatic solutions is, at least, of quite frequent occurrence.

The article by Bailey and Grabham is perhaps the most detailed and convincing in showing how the albitization occurs and how its origin may well be connected with the magma which produced the rocks affected. Recently (1923) W. R. Browne drew attention, in a brief paper, to the occurrence of the phenomenon in many of the Upper Palaeozoic igneous rocks of New South Wales, and in the present investigation the writer has encountered numerous examples of albitization. It is thought here that the change has been one of magmatic origin, produced by solutions connected with the extrusions of the lavas, and after a description of the phenomenon, the reasons for this view will be given.

In the rocks examined the replacement is found in non-vitrophyric types. Thus the well known pitchstones occurring towards the base of the Kuttung Series are immune from albitization. The more basic of the lithoidal types are also free from the change. In those lithoidal types affected, both plagioclase and orthoclase may suffer replacement, whether they be phenocrysts or in the groundmass, although in the case of the latter it is difficult to make out the extent of the change satisfactorily.

In general the albite attacks the phenocrysts by working along the cleavage cracks and around the margins. At times the plagioclase phenocrysts may be undergoing change without reference to any optical directions, and in such a case, had conditions permitted, a complete pseudomorph would have resulted. At other times, however, a particular zone or zones in the plagioclase may be albitized while the rest of the mineral is unaltered; in such cases, the more basic zones suffer. Frequently a little calcite is found associated with the albite, and in almost all cases there are scales of sericitic mica, which may be the result of normal weathering of the albite itself. How far the calcite may represent the residual lime left after replacement is not clear.

One characteristic of the secondary albite is its spongy appearance, due possibly to the aggregation of tiny patches of albite which, though probably in optical continuity, are mixed with a certain amount of impurity and possibly with ultramicroscopic areas of residual basic plagioclase.

In the change of orthoclase to albite, the ragged outline of the albite working from the margin across the crystal is very characteristic, and often the albite has a dirty yellow colour in ordinary light, which may be due to the presence of some limonitic material.

The groundmass of certain rocks, when cryptocrystalline, shows a certain amount of replacement by albite which occurs in short prisms, and when pumiceous the ground may show a kind of selective albitization, the cusp-shaped bodies being partially or wholly replaced.

In some cases one can find sufficient unreplaced material to permit the determination of the original composition of the lime-soda felspar, but at times the albitization has, as far as can be seen, been complete, and the consequences of such a circumstance are very important, especially in connection with the question of the relations of the various rocks.

That the process of albitization in these rocks has been of magmatic origin, as specified above, seems to be established from the following criteria: The change has been selective, affecting those rocks which are at least as acid as the Martin's Creek andesite. The lithoidal pyroxene-andesites, which are the most basic in the series, have not been altered in this manner. In regard to the immunity of the glassy andesites from albitization, it is not thought that this point has any significance in connection with the origin of the phenomenon, because, whatever the nature of the solutions involved, it is probable that these glasses offer little means of access for the waters, but in the case of the lithoidal pyroxene-andesites, they, being in direct association with albitized rocks, should likewise show evidence of having been affected, if the solutions were meteoric.

Then again, the extent of the phenomenon does not in any way correspond with the extent of atmospheric weathering seen in any of the albitized rock masses, nor is the albitization to be found more complete near cracks and fissures. For example, in very fresh specimens taken from the deepest portions of the quarries in the andesite at Martin's Creek and the keratophyre on the Williams River below Clarencetown, the albitization is quite well-developed, being in the latter case such as to have replaced completely the original lime-soda felspar. Also, in rocks which are strongly albitized there is often an absence of the effects of weathering in the minerals.

Further, there is an almost constant association of chlorite with the albite, and it is difficult to imagine how chloritization of plagioclase, and even of orthoclase, as in one or two instances, would be brought about by meteoric solutions.

Thus the process of albitization in these rocks seems to be of magmatic origin, occurring after the consolidation of the lavas, but being the effect of the operation of solutions directly connected with the lava magmas. That is to say, the process is a "deuteric" one as defined by Sederholm (1906) and its origin is indicated by the term "late-magmatic" as used recently by Browne (1925). Holmes's definition (1920) of Sargent's term "autometamorphism" (1917) would also include the process of albitization.

Chloritization.—The occurrence of chlorite in certain of the Kuttung rocks is such as to place doubt upon its origin being simply connected with weathering. Thus in certain andesites and toscanites, a replacement of plagioclase by chlorite occurs, the latter confining itself to one or more zones, and rarely completely replacing the former. Elsewhere in the groundmass of these rocks, patches and veinlets of chlorite are found undoubtedly indicating selective replacement. In all cases of the presence of chlorite in the manner indicated here, albitization was found to have occurred. Bearing in mind the chemical composition of the chlorite minerals, and having regard to the constant association of albitization and chloritization, it seems reasonable to regard the former as being, like the latter, of late-magmatic origin.

Kaolinization.—In various rocks throughout the Kuttung Series, kaolin occurs in notable amounts replacing felspar phenocrysts and also groundmasses which originally have been pumiceous and glassy. In many cases the field evidence is somewhat against the kaolin having been produced by the action of surface waters, although it must be understood that there are numerous cases where it is clear that the kaolin has developed by rock decomposition. Of the former cases, two can be cited. In a quarry near Seaham, specimens taken from about fifteen feet below the ground level show much more kaolinization than those close to the surface, and separating the kaolinized rocks over an appreciable extent is a band higher up, which has a groundmass in which kaolinization is almost absent. In the case of the Williams River keratophyre quarry, one finds a greater proportion of kaolinized felspar as one proceeds downwards, and the kaolinization is sometimes sporadic in occurrence, and found not close to joints.

This field evidence, then, seems to suggest that the kaolin has been produced by the action of magmatic solutions, and in support of this one finds that albitization and chloritization are often associated features.

That kaolin may be of deuteric origin seems to be demonstrated by certain features exhibited by the Prospect intrusion (see Browne, 1925), and it occurs in some rocks on the South Coast of New South Wales in such a way as again to indicate origin by the action of late-magmatic waters.

Devitrification, and the Relation between the Glassy and Lithoidal Andesites.

From the petrographical examination of the rocks it is clear that devitrification has occurred in a large number of cases. Thus, pumiceous material, originally glassy, has been affected and altered into material with cryptocrystalline texture. One can frequently see unaltered patches of pumiceous matter in a rock which has not undergone complete devitrification. This residual glassy content is different from that occurring as streaks in some rocks, such as the

Martin's Creek andesite, where it appears that the glass is a fraction that did not have an opportunity to crystallize like the bulk of the rock. Then, in certain instances, it was noticed that some lithoidal rocks showed a sort of perlitic cracking, which almost certainly occurred during the rapid solidification of a glassy rock.

The question of the time of devitrification is one of interest and of some difficulty. Judd (1889) described processes which had operated in rocks with vitrophyric groundmasses whereby phenocrysts actually enlarged themselves at the expense of the glass, the process being a kind of devitrification, regarded as secondary, but occurring at no great time after the congealing of the lava. In describing the origin of the pitchstones of Mull, Anderson and Radley (1917) showed by chemical evidence that the lithoidal rocks appeared to be the devitrified products of the pitchstones. These authors distinguished between primary and secondary devitrification, the former occurring just after the consolidation of the rock and the latter being a long process working for ages after solidification.

Bonney and Parkinson (1903) described two types of devitrification, one primary and one secondary, but in giving detailed descriptions of each of these, did not explain clearly their time relations, although Bonney elsewhere (1885) has indicated his belief that the primary devitrification occurred during cooling and the secondary type took place long afterward. Harker (1909, p. 226) did not agree with those who postulated primary and secondary devitrification, and inclined to the view that it was a process of long duration. In the case of the Kuttung lavas there is little evidence available to help one to decide when the change occurred, but in view of the fact that certain authors have maintained that so-called primary devitrification occurs immediately following the consolidation of a glassy rock, it might be worthy of consideration whether the change has, in the Kuttung lavas at all events, had some relation to the activity of late-magmatic solutions. The possibility of a lava being devitrified would then depend to a great extent on the chemical composition and the physical conditions attending its cooling, and thus it would be reasonable to expect to find certain glassy rocks practically wholly unaffected, in association with lavas evidencing devitrification, an association which occurs in the Kuttung terrains.

This discussion of devitrification leads us to enquire into the question of whether the lithoidal varieties of amphibole- and pyroxene-andesites are the devitrified equivalents of the glassy andesites, which are found in close association with them, and which, mineralogically, are in each case similar.

Anderson and Radley demonstrated that the felsites of Mull were chemically very similar to the pitchstones, except as regards the content of combined water, and were convinced that the former had arisen from the latter by the escape of some of this water. The chemical evidence in the case of the hornblende-biotite-andesites now being considered does not support the view that they have been derived from glassy andesites by devitrification. This may be seen from the chemical data given below:

	I.	II.
SiO_2 ..	64.88 ..	66.38
CaO ..	3.00 ..	4.11
Na_2O ..	5.41 ..	3.55
K_2O ..	2.79 ..	1.72
H_2O ..	1.63 ..	4.56

I. Biotite-hornblende-andesite, Martin's Creek.

II. Hypersthene-bearing biotite hornblende andesitic glass, Tumbledown Creek, east of Martin's Creek. Analyst G.D.O.

Of course, the wide variation in the case of the values for soda is to some extent due to the fact that albitization occurs in No. I, but the difference in the values of potash is too marked to allow of No. I being the devitrified product of No. II. Chemical examination of the two phases of the pyroxene-andesite has not been made, but the association of very similar rocks at Currabubula has been commented upon by W. R. Browne (1920, pp. 415-6).

Concerning the field evidence it is to be pointed out that the two varieties of the biotite-hornblende-andesite were always found to be sharply bounded. Thus in a railway cutting to the east of Wallarobba, there is the following succession: lithoidal andesite 6 feet, glassy andesite 2½ feet, lithoidal andesite 12 feet; all the bounding surfaces being sharply defined.

In the case of the hypersthene-augite-andesite one was not able to delimit in the field the extent of the two phases, but it appeared as if there were separate flows of the two varieties.

Microscopically there does not seem to be much in favour of the lithoidal andesites having been derived from the glassy types. Thus in the case of the pyroxene group, the groundmass of the stony phase is spongy in appearance, and under crossed nicols with high magnification there are no signs of residual glass. Also in the lithoidal phases of the mica-amphibole-andesites there are present streaks, rather than patches of glass, strung out in the direction of flow which, in the writer's opinion, indicate original heterogeneity of the magma material at the close of the intratelluric crystallization.

Mineralogical and Magmatic Relationships.

The effect of late-magmatic processes upon many of the rocks has made a consideration of their relationships a matter of difficulty, but in spite of this, one can see to some extent how the various lavas are genetically connected from a mineralogical point of view, while a satisfactory understanding of their magmatic relations is not possible with the data at present available.

Mineralogical Relationships.—Although quartz has been noticed in the Martin's Creek type of andesite, it is doubtful whether it really belongs to the rock, probably being xenocrystic. This mineral makes its appearance in the quartz-keratophyres and dacites, increasing in importance in the toscanites, till in the dellenites and rhyolites it is conspicuous. In some cases it is present in the groundmass of certain acidic rocks.

Plagioclase, where unaltered, shows a gradation from labradorite in the pyroxene-andesites to andesine in the mica-amphibole-andesites and toscanites, becoming acid andesine and oligoclase in the dellenites. It is not clear whether any primary albite occurs in the soda rhyolites.

Orthoclase is very subordinate in the dacites, but becomes an important constituent in the toscanites and dellenites, and its further increase is seen in the sodipotassic and potassic rhyolites.

Of the ferro-magnesian minerals, biotite is the most widespread, being found in all groups of rocks except the pyroxene-andesites, and hornblende is also fairly widespread, being present in the Martin's Creek type of andesite, the Williams River keratophyre, in some of the dacites, and in both the Mt. Gilmore and Paterson types of toscanite and andesite, as well as in certain rhyolites.

Augite and hypersthene have their best development in the pyroxene-andesites, but both occur along with biotite and hornblende in a glassy andesite from

Portion 99, Parish of Barford; this rock being a connecting link between the two main groups of andesite.

The iron ores in the rocks comprise magnetite and ilmenite. Often both are present, whereas one or other may occur alone. In this connection ilmenite is especially characteristic of the dacites.

Apatite is of almost universal occurrence, but it is of greater abundance in those rocks which contain considerable ilmenite. Zircon is of quite frequent appearance in the hornblende-andesites, but only occasionally met with in some of the other types.

Chemical Relationships.—With the data to hand at present, and in view of the presence of albitization, one cannot achieve much in the way of examining the magmatic relations of the rocks under discussion.

The salient features of the chemical evidence are as follow: The rocks which have been analysed show fairly high silica percentages, even in the case of the rocks with andesitic characters. Thus the andesites contain from 64.88% to 66.38% of silica, the quartz-keratophyres and dacites about 67%, and the dellenites, which are closely allied to sodipotassic rhyolites, have as much as 72% or 73%. Concerning the alkalis, potash has been found as an important constituent in all rocks analysed. Indeed it would appear that, were it not for the presence of albitization, it is probable that the Kuttung rocks in this district would show a general possession of a sodipotassic or in some cases a "dopotassic" character.

Magnesia is low in most rocks, although it would probably be found to be fairly important in an analysis of the pyroxene-andesite. A fair amount of titanium and also appreciable amounts of manganese are always present, while phosphorus varies considerably, sometimes being only present as a trace.

What was the composition of the original magma, from which the Kuttung lavas were derived, is a question which it is difficult to answer. Chiefly from field evidence, strengthened by a consideration of the chemical and microscopical data, one must say that the suggestion put forward by Dr. Browne that the hornblende-andesites may represent the composition of the original magma which later became differentiated into divergent types, does seem to be likely to prove correct.

Spherulitic and Allied Structures.

In the groundmasses of some rocks examples of spherulitic crystallization are found. The spherulites are often very minute and in general have never been found to attain any great size as is the case in certain volcanic rocks in various parts of the world. Sometimes there are present structures of the same nature as the spherulites, but these are not always circular in cross-section, representing rather growth from a series of points linearly disposed. Among the most frequent of such structures are some which may be called axiolites, being very similar in structure to those figured by Iddings (1910, p. 240). Often the spherulites are aggregated together so as to form an integral part of the rock, but at other times these aggregations may be present as inclusions. Examples of the latter cases are to be found in a felsite occurring to the east of the Railway Line about one mile south of Martin's Creek. *Specimen 26** from this locality shows an abundance of inclusions, many being entirely composed of aggregations of spherulites and axiolites, the spherulites averaging ¼ mm. in radius. They are

* Numbers refer to specimens in the writer's collection.

set in a groundmass which is somewhat kaolinized and haematitized. Under the microscope, the material composing the spherulitic structures is, for the most part, felspar which has a refractive index less than that of Canada balsam, but there is also some silica in association with the felspar.

With regard to the time of development of these structures, it is to be pointed out that in some of the rhyolites the spherulites are found across the flow lines. This may mean either that the spherulitic crystallization occurred after consolidation of the material showing the flow structure, or, at all events, after this material became too viscous to move. Although the latter seems the more probable, Harker mentions (1909, p. 275) cases of the former.

Judd also (1889), described certain pseudo-spherulitic structures, which he considered developed after the solidification of the rock, while Parkinson (1903), in discussing Iddings's work on the Yellowstone Area (1885-86 and 1899), contends that there may be more than one period of spherulitic crystallization in a glassy rock, some spherulites developing before the perlitic cracking which is often characteristic of obsidians, and others appearing after the consolidation of the glass when its perlitic cracking was complete.

Autobrecciation.

A feature of many of the Kuttung lavas of acid alkaline composition is the presence, in the groundmass, of brecciated structures which have originated during the solidification of the mass. This type of structure has been termed autobrecciation. The effects of its operation on a fairly large scale are to be seen in the features exhibited by certain flow-breccias in the Langlands section which have been described in a former paper (1922, p. 173).

The autobrecciation has been observed only in the acid lavas and especially those which are sodic. It is clearly related to the high viscosity of such magmas, and has been commented upon by a number of authors. Woolridge has described the petrography of an interesting set of rocks from Llanwrytd, Wales (Stamp and Woolridge, 1923), which are dominantly sodic, and he has emphasized the prevalence of pyroclastic material and the existence of autobrecciation. These rocks are of terrestrial origin and it would seem that subaerial conditions should be favourable to the production of brecciated structures in acid sodic lavas, by the breaking up of a magma crust and the subsequent corrosion of the fragments in the residual molten material. But J. F. N. Green (1919) argues that autobrecciation is a feature of submarine flows of certain chemical composition.

Associated with the Kuttung lavas showing evidence of autobrecciation is the occurrence of flows in which there is an abundance of vesicular glassy material, often now devitrified.

Petrographical Descriptions of the Kuttung Series.

Nomenclature of the Rocks.

Before proceeding with the petrographical details, it is pertinent to say something about the nomenclature of the rocks. As has been pointed out above, the process of albitization, whereby felspars and other material become replaced by albite of late-magmatic origin, has affected many of the rocks and in some cases obscured their relationships. In the cases where the albitization has been partial, the original identity of the rocks is often determinable, but when the change has been complete, with reference to the primary felspars, there is generally no clue to the original nature of the rocks and they have to be referred to as soda rhyolites or keratophyres. It has been decided, therefore, in the case of the altered rocks to name the rock according to its original identity where possible, and to mention the possibility of a rock having had its felspathic constituents completely albitized, where such is suspected, the rock in such case being named according to its present constitution. Attention has been drawn by W. R. Browne to the difficulties arising out of the albitization of igneous rocks (Browne, 1923).

Then, concerning the acid and sub-acid lavas, one has had to make use of the terms dellenite and toscanite for the following reasons: There are a large number of massive igneous rocks in the Kuttung series which possess considerable variety and which might all come under the two broad categories, rhyolite and dacite. To apply either of such terms to numerous rocks, however, would be impracticable in connection with the present petrographical discussion, since fine distinctions between important flows would not be recognized, and confusion would result. The use of the terms toscanite and dellenite (both very much the same as quartz-trachy-andesite, but each much shorter and more serviceable) permits the recognition of very slight gradations in chemical composition: thus the term toscanite has been applied to rocks where there is a fair amount of orthoclase, as well as considerable plagioclase which is basic andesine or acid labradorite, and the term dellenite applied to types where there is orthoclase, and plagioclase of the composition oligoclase or very acid andesine, quartz in both instances being dominant but not very excessive. The increase of quartz and the absence of orthoclase, always accompanied by an acidification of the plagioclase, produces a soda rhyolite, and the greater abundance of orthoclase places the rocks in the category of potash rhyolite. In connection with those rocks dominantly sodic, the name keratophyre has been applied to rocks which show much phenocrystic albite with stout prismatic habit, and a sort of coarse orthophyric fabric, or an approach thereto. Soda rhyolite has been reserved for acidic albitic rocks which have extensive cryptocrystalline groundmasses.

In the following descriptions the dominant types in each section will be considered in detail, the less important representatives being treated only with reference to their variation from the main types.

The distribution of the various types described below has already been indicated in the former paper and will not be repeated here.

Andesites.

The andesites comprise two fairly distinct groups, characterized by biotite and hornblende on the one hand, and augite and hypersthene on the other. There are also some rocks which act as connecting links between the two series, in that they contain both amphibole and pyroxene. In each of the two main groups there are glassy and lithoidal varieties.

Mica-amphibole Group (Martin's Creek Type).

Glassy Varieties.

Megascopical characters: These rocks are black in colour, with a resinous lustre, possessing phenocrysts of felspar and biotite and a number of yellow streaks.

Microscopical characters: *Specimen 80*, from the Railway Cutting three-quarters of a mile east of Wallarobba Station, shows the presence of hornblende, plagioclase and biotite and very subsidiary pyroxene, apparently hypersthene, also apatite and magnetite set in a groundmass which is almost entirely glassy. The felspar individuals are fresh but cracked noticeably, and possess a tabular habit and a composition close to Ab_3An_2. The hornblende is quite fresh and shows the (110) cleavage rather well, while biotite, although fairly well-formed, evidences bleaching and some alteration. One or two sections of quartz may be of xenocrystic origin.

The vitrophyric groundmass shows fluidal fabric and is noticeably cracked as a result of pressure following solidification. There are present a number of microlites of felspar and tiny magnetite crystals as well as small patches, which under high magnification appear to be greenish decomposition products.

Lithoidal Varieties.

Megascopical characters: These rocks vary in colour from light blue and grey to dark blue. Phenocrysts of hornblende and plagioclase, the latter often showing a black core, occur in varying amount in a dense dull-lustred groundmass which possesses some reddish blotches. The rocks fracture in various ways, according to the nature of the texture and mineralogical arrangement.

Microscopical characters: *Specimen 1*, from the quarry formerly owned by the State Metal Quarries, Ltd., shows the following primary minerals present: plagioclase, hornblende, biotite, magnetite, ilmenite (?), apatite and zircon. These are set in a groundmass which makes up two-thirds of the rocks.

The plagioclase has the composition Ab_3An_2 (andesine) and possesses a tabular prismatic habit. It is occasionally zoned and the grainsize is variable and up to 2 mm. in diameter. Albite, carlsbad and pericline twinning are all present, the last of these being rare. Albitization and chloritization (see Plate xxiii, No. 2) of the andesine have occurred and scales of sericite have developed by decomposition, but these features are not present to the extent of obliterating any one grain. The albite has used the imperfect cleavage cracks to facilitate its attack upon the more basic material, and in some cases has replaced the central portions of the andesine first of all. The chlorite is found pseudomorphing the core of the plagioclase in most cases, while at other times it has selected some zone or zones which are completely replaced.

Hornblende occurs subidiomorphically and shows a fair amount of resorption. The cleavage parallel to (110) is well developed and the pleochroism is strong. Biotite, which is present in slender pieces, is very much altered by chloritization and has been resorbed with the production of magnetite.

Primary magnetite certainly occurs and there seems to be some ilmenite also. The apatite and zircon call for no special remarks, except to point out that the latter is subordinate to the former. Quartz occasionally occurs in this andesite, but under the microscope appears to be of a xenocrystic nature. The field evidence, however, shows that towards the base of the andesites at Martin's Creek the number of quartz individuals increases.

The groundmass shows lines of flow very well and consists of streaks of brownish glass and patches of cryptocrystalline material. It would appear that this glassy matter is the expression of original heterogeneity of the magma, rather than that partial devitrification has occurred. The red patches referred to above are due to staining by haematite derived from nuclei of iron oxides.

Specimen 2 is somewhat lighter in colour and shows more phenocrystic hornblende than does *No. 1*. In thin section it is similar to *No. 1*, but there are some completely albitized phenocrysts.

Specimen 3 differs from *No. 1* in that the ratio of groundmass to phenocrysts is smaller, and there is a coarser grainsize in the microfelsitic portions of the groundmass.

Specimen 4 is of a dark blue colour and possesses a very irregular fracture. The plagioclase individuals are ill-formed, and there is an almost entire absence of hornblende. Microscopically, it is seen to differ widely from the other varieties. Glassy material is almost absent from the groundmass and the spongy felspathic content is of a coarser texture than has been the case hitherto. The phenocrysts of andesine are somewhat replaced by albite and chlorite and are ragged in outline. Apatite and zircon are quite distinct.

It may be mentioned here that in his account of the Martin's Creek andesite, M. Aurousseau (1915) recorded the presence of hypersthene. The present writer has not observed this mineral in any of the many slides of the andesite which he has examined.

Pyroxene Group.

Glassy Varieties.

Megascopical characters: These, in hand specimen, are black rocks possessing a subdued resinous lustre and a fair amount of yellowish-coloured plagioclase as phenocrysts. A little ferro-magnesian material is also discernible.

Microscopical characters: Phenocrysts of plagioclase, hypersthene, augite, magnetite and apatite are set in a brownish-grey glass. The plagioclase is tabular in habit and shows twinning according to the albite, carlsbad and pericline schemes. There is a little zoning present, and many inclusions are seen. Some of the inclusions are arranged zonally and may consist of portions of the groundmass, yet the edges of the felspar are not corroded to any extent. The composition of the mineral is that of basic labradorite. The (001) cleavage is only poorly developed in some individuals. Very noticeable is the absence of albitization and chloritization. Hypersthene is more abundant than augite and shows fairly distinct pleochroism, a fairly good cleavage and the presence of numerous cracks. Magnetite is generally found as inclusions in the hypersthene. Felspar inclusions are rare and apatite only occurs occasionally. The hypersthene is only slightly altered and then to a brownish-green silicate, possibly anthophyllite. The augite is subidiomorphic, up to $1\frac{1}{2}$ mm. in diameter, and possesses twinning, being of a brownish-grey colour.

The groundmass is almost entirely glassy, but under the high magnification is seen to include a number of tiny patches of a greenish substance, which is probably derivative from a ferro-magnesian mineral, and some tiny felspar crystals, the remainder being brown glass. In one slide there was present what appeared to be an inclusion of a rock, essentially similar in composition to the host, that is to say, composed of augite, hypersthene and plagioclase, possessing an even grainsize and showing no decomposition. This probably represents a cognate xenolith which has been torn by the magma from some mass which crystallized under intratelluric conditions.

Lithoidal Varieties.

Megascopical characters: These varieties are dark blue to black in colour, the felspar phenocrysts being very readily seen and the pyroxene only with difficulty. The groundmass possesses a dull lustre.

Microscopical characters: In thin section one sees the same phenocrystic constituents as in the glassy varieties. The felspars are tabular in habit and variable in grainsize, the maximum being about 3 mm. in diameter. Zoning, and twinning according to the albite and carlsbad schemes, are present and the composition of the plagioclase is Ab_2An_3, labradorite. Hypersthene is noticeably changed, the alteration developing around the margin of the grains in the first place and then along the cracks. The product seems to be something related to uralitic hornblende. Augite is not very conspicuous and is quite fresh. Apatite is present in acicular crystals.

The groundmass is distinctive in its appearance and consists of a spongy mass that extinguishes in patches on rotation of the microscope stage. There is not the felsitic appearance which characterizes so many of the groundmasses of the other Kuttung rocks. Examination of this groundmass under the high power shows the presence of tiny green patches which clearly are pseudomorphs, together with abundant iron ore individuals all set in a felspathic mass which shows undulose extinction. There is no glass present, and in a general sense the groundmass is not heterogeneous.

Amongst the pyroxene-andesites there is very little variation within the two groups and foregoing descriptions hold for almost all the occurrences in the area.

Transitional Types of Andesites.

Intermediate in character between the amphibole- and pyroxene-andesites come certain rocks of limited distribution; *Specimen 327*, from the northern side of a ridge in Portion 99, Parish of Barford, is typical of these rocks.

Megascopical characters: This is a greenish-black rock with a greasy rather than a pitchy lustre. Phenocrysts of hexagonal biotite and another ferro-magnesian mineral are clearly seen, also some tiny laths of felspar.

Microscopical characters: In thin section one sees phenocrysts of plagioclase, biotite, hornblende, augite, hypersthene, and quartz set in a glassy groundmass, which contains a few felsitic inclusions. The rock shows a certain amount of cracking and there is also marked flow structure. Some of the phenocrysts are shattered as a result of pressure acting after the rock consolidated. The plagioclase, which is acid labradorite, shows a tabular habit, and albite and carlsbad twinning. Hypersthene is not abundant and is non-pleochroic, but shows alteration to a greenish substance. The augite is present in small equidimensional crystals and is fairly fresh, being of a grey colour. Hornblende is a fairly important constituent and shows the prismatic cleavage fairly well developed. Pleochroism is noticeable and decomposition is practically absent. The biotite is both bent and bleached at times, but it has not been resorbed. The quartz appears to be xenocrystic in origin, in view of the fact that it generally shows an association with a certain amount of cryptocrystalline material, which is quite similar to the groundmass of the included fragments, but unlike the glassy groundmass of the main rock. It is to be noted, also, that in one slide of these rocks quartz was almost absent and so also were the rock inclusions. The groundmass of *327* is brownish in colour and almost completely glassy.

Chemical composition: A chemical analysis of *Specimen No. 1*, a lithoidal andesite from Martin's Creek and also a partial analysis of *Specimen 327*, a transitional type of glassy andesite, were made. These are tabulated below together with an analysis of another specimen of andesite from Martin's Creek, quoted by Mr. Sussmilch (1923, p. 24).

It will be seen immediately that in analysis No. I there is evidence of the rock having been albitized. The composition of the plagioclase calculated from the chemical data comes out at about oligoclase of the formula Ab_4An_1, while the unaltered felspar seen in parts of the rock under the microscope was andesine of the composition Ab_3An_2. In the case of analysis No. III there is evidence that the albitization has been less extensive. The figures for the rock from Tumbledown are of interest, showing the high content of combined water, and values for lime and the alkalis which are more normal for an andesitic rock. These circumstances are due to the fact that late magmatic processes have not affected the rock. From a determination made upon the alumina of this pitchstone it was quite clear that there was sufficient present to allow all the lime to be calculated as anorthite, and with this information the plagioclase felspar in the rock has been found to be of the composition Ab_3An_2, this being about the same as that of the unaltered plagioclase in the lithoidal andesite (*Specimen 1*).

	I.	II.	III.
SiO_2	64.88	66.38	64.20
Al_2O_3	16.18		16.88
Fe_2O_3	1.52		1.90
FeO	2.43		2.52
MgO	1.21		.66
CaO	3.00	4.11	3.14
Na_2O	5.41	3.55	4.41
K_2O	2.79	1.72	3.52
H_2O+	1.63	4.56	1.79
H_2O-	.50	1.04	.31
TiO_2	.89		.65
P_2O_5	trace		.13
CO_2	trace		.03
MnO	.05		—
	100.49		100.14

Specific gravity of I = 2.642 at 16.5° C. Magmatic name for I = Lassenose.

I. Andesite, lithoidal variety, *Specimen 1*, Martin's Creek, N.S.W. Analyst, G. D. Osborne.

II. Andesite, glassy variety, *Specimen 327*. Tumbledown Creek, near Martin's Creek, N.S.W. Analyst, G. D. Osborne.

III. Andesite, Martin's Creek. Analyst, W. G. Stone.

Dacites.

Megascopical characters: The dacites are in general of a light colour, chiefly pink and cream, although darker varieties occur in the neighbourhood of Glenoak. The fracture of the rocks is generally very even, but becomes quite irregular in those types which contain a number of inclusions and spherulitic structures. The minerals visible in hand specimen comprise plagioclase, quartz, biotite, and sometimes orthoclase. At times the former two are very conspicuous and at other times they, as is generally the case with the latter two, are quite inconspicuous. The lustre of the rocks is dull, the appearance of the groundmass quite felsitic. The inclusion-bearing types are, like the massive rocks, of fairly wide distribution, but a notable occurrence of the former is near the foot of Mt. Johnstone, about 1¾ miles from Paterson. Here one finds a great variety in the appearance of the dacites, although the parent rock is fairly constant in composition.

Microscopical characters: The minerals discernible under the microscope comprise quartz, plagioclase, biotite, orthoclase, ilmenite, magnetite, hornblende, zircon, and apatite. The plagioclase varies considerably in grainsize, being up to 1½ mm. in diameter. The twinning is chiefly according to the albite law, but sometimes after the carlsbad law as well. The habit is generally tabular, but at times almost prismatic. The chemical composition of the felspar varies from basic oligoclase to very acid labradorite. Decomposition to kaolin has progressed to a fair degree in many cases, and fresh felspars are rarely to be seen. Some replacement by albite, almost certainly of deuteric origin, is common and may have occurred to the extent of half the original crystal being replaced.

Quartz is generally cracked and corroded, but always shows sharp extinction. It varies considerably in grainsize and when in the groundmass is very small indeed. Orthoclase, of course, is only of infrequent occurrence and then in a very subordinate amount. There is generally a good (001) cleavage present, and almost complete kaolinization is always to be seen.

Biotite is fairly common in one or two slides, but sparingly present in the majority. Weak pleochroism and evidences of having been strained are generally seen, while resorption, with the production of magnetite, is only a rare feature. Hornblende is not a constant constituent, but is always fresh and ragged in outline. The ilmenite is quite a common mineral in the dacites, while magnetite only occurs rarely. The former shows typical alteration to leucoxene, and haematite is invariably found around the margins of the magnetite units. In two of the rocks tiny zircons have been found, and a very little apatite occurs in the majority of the dacites.

The groundmasses of the rocks vary considerably. Sometimes the texture is quite even and entirely cryptocrystalline, consisting most probably of felspar and quartz. At other times there is a variation in the nature of the groundmass from place to place. Thus there may be spherulitic patches and cryptocrystalline areas as well as some residual glass. No entirely glassy groundmasses have been found, although some rocks possessed a considerable amount of vitreous material. Devitrification has occurred in some specimens, especially those containing a pumiceous groundmass. In these cases the cuspate bodies left after the collapse of pumice bubbles have been changed to felspar and then kaolinized.

Examination of *Specimen 5* and certain slides kindly lent by Mr. Sussmilch, all from the little quarry at the foot of Mt. Johnstone, shows that one can at times obtain dacites free from enclosures and at other times it is difficult to do this. The rocks all have a typically felsitic appearance and show considerable amounts of phenocrystic biotite and quartz as well as plagioclase. The plagioclase varies from andesine, $Ab_{11}An_9$, to labradorite, Ab_2An_3, and shows a tabular prismatic habit. There is a little albitization in the case of one rock. The biotite is bent and considerably altered while the quartz shows corrosion and inclusions of the groundmass. The groundmass is always pumiceous and in some rocks extensive silicification has occurred while devitrification is evidenced in certain cases. Haematite, which is the result of infiltration, is often present, causing a pink colour to be imparted to the rocks. In all cases the rocks are dacites, except in one case where there is a tendency to become a rhyolite.

The rock inclusions in the dacites of this locality comprise obsidian, rhyolite and soda felsite. These are not cognate with the parent rock. In the groundmass of some of the dacites, however, there are present spherulites, which occur in separate little masses surrounded by a border of finely divided silica. These composite inclusions do appear to be more of the nature of cognate inclusions.

Specimens 171 and *495* are from Mt. Gilmore and show a large number of inclusions. In these rocks the felspar becomes as acid as basic oligoclase.

Specimen 415 from the southern part of the Glenoak section is distinctive on account of its blotchy appearance. This, under the microscope, is seen to be due to the prevalence of haematite in certain parts of the groundmass. This rock also evidences a little albitization of the plagioclase.

Chemical composition: A partial analysis, by the writer, of a representative of the dacitic rocks, described above, and occurring at the little quarry near the foot of Mt. Johnstone is as follows:

SiO_2	67.76
Al_2O_3	12.89
CaO	1.16
Na_2O	2.32
K_2O	1.88

The composition of the plagioclase, calculated from the above data is andesine of the formula $Ab_{76}An_{24}$. This rock is low in alkalis and the specimen was free from albitization. The silica percentage is of the same order as the values found in the andesites given above, and a complete analysis would almost certainly find its place in the same class and order of the quantitative classification as that in which the andesites are placed.

Quartz-Keratophyres.

Albitization has been detected in the rocks described under this heading, and it is probable that all the albite which causes the rocks in their present condition to be called keratophyres, came along during the late-magmatic period.

The most important examples of these occur right throughout the area, and constitute the Williams River type. The best exposure of this type is in a quarry on the left bank of the Williams River below Clarencetown.

Megascopical characters: The quartz-keratophyres are very constant in their appearance. When fresh the colour is a dark blue, but fresh specimens are rarely obtained and the prevalent colours of the somewhat weathered outcrops are fawn and light green. Flow structure is visible in the arrangement of the phenocrysts which include quartz, biotite and plagioclase. The abundance of biotite often imparts to the rocks a spangled appearance. The groundmass is dense and dull lustred.

Microscopical characters: The rocks show a uniformity in microscopical features, there being in the case of some flows a slight change to a finer texture in the upper portions. *Specimens 131* and *262* from the Mt. Gilmore district are of the Williams River type, and may be taken as typical of the rocks.

The phenocrysts make up 60% of the rock and are themselves present in the following proportions: felspar 60%, quartz 20%, biotite 13%, hornblende 4%, iron ore 2%, apatite less than 1%. In *No. 131* the felspar is all albite and this slide was used in 1922 when the rock was named a biotite-quartz-keratophyre. A slide of *No. 262*, since examined, shows the presence of some residual more basic felspar in the central portions of some of the albite phenocrysts, so that it is very likely that the whole of the albite is of late-magmatic origin. The habit of the felspar is stout prismatic and the lamellar twinning is imperfectly developed. The (001) cleavage which has never been well developed, is obscured by the later albitization. Along some of the cracks sericitic mica has developed as a result of weathering. Associated with the albite is chlorite, which occurs as patches in the felspar and in the groundmass. The biotite is of a brown variety and shows streaky bleaching. Many pieces have been bent, and along the cleavage cracks are found veinlets of haematite.

The quartz is present in equidimensional sections and shows many pseudo-inclusions of the groundmass. Hornblende is not a very prominent constituent, although its presence is significant. It is of a pale green colour and shows pleochroism of medium intensity. The prismatic cleavage is poorly developed, as also is the twinning which has its plane of composition parallel to (100).

	I.	II.
SiO_2	67.06	67.71
Al_2O_3	15.95	15.24
Fe_2O_3	1.78	1.48
FeO	2.37	1.89
MgO	1.87	.46
CaO	1.98	3.00
Na_2O	4.62	5.87
K_2O	2.01	1.81
H_2O+	.65	1.89
H_2O-	.44	.39
P_2O_5	.28	trace
TiO_2	.40	.47
CO_2	absent	absent
SO_3	absent	—
Cl	trace	—
SrO	absent	—
MnO	.39	—
	99.80	100.21

Specific gravity of I = 2.62 at 16° C.

I. Quartz keratophyre, Williams River, near Clarencetown, N.S.W. Analyst, G. D. Osborne.

II. Quartz keratophyre, Church Hill, Currabubula, N.S.W. Analyst, H. Yates.

The iron ore is mostly decomposed and appears originally to have been of both varieties, magnetite and ilmenite. Apatite with acicular habit and a stray section of zircon are present.

The groundmass contains a fair amount of glassy material, but for the most part is cryptocrystalline. The arrangement of the felspar phenocrysts, especially on account of their stout prismatic habit, is such, when the groundmass is very subordinate, as to give rise to an approach to a coarse orthophyric fabric.

Similar rocks to those just described occur higher up in the stratigraphical succession, examples of such being *Specimen 263* in the Mt. Gilmore section, and *Nos. 367* and *402* occurring near Glenoak.

Chemical composition: Chemical analysis has been made of *Specimen 131* of the quartz-keratophyre from the Williams River Quarry and is tabulated above, and with it is placed an analysis of a quartz-keratophyre from Currabubula. These two rocks have different textures and different modes of occurrence in the field, and it is premature to enquire into the question of whether they can be correlated one with the other, but the chemical data give evidence of a certain amount of general similarity, in that the rocks are both sodic and of about the same acidity.

Toscanites and Dellenites.

The rocks coming under this heading are fairly acidic in nature, but they differ entirely in texture and to some extent in the nature of the phenocrysts, from many of the rhyolites. It has been found that a certain flow will in one place be a toscanite and in another place a dellenite due to a gradual variation; but cases of a unit maintaining its toscanitic or dellenitic nature throughout the whole of its occurrence have been seen.

The two most important sets of rocks in this group are those known respectively as the Paterson and Mt. Gilmore types of toscanite and dellenite. Microscopically the two types are somewhat similar, but there are certain differences and it will be well to describe each type separately.

Mt. Gilmore Type.

Megascopical characters: The general body colour of the rock is a brown, the two varieties of felspar, plagioclase and orthoclase, being quite conspicuous, as also is quartz, while subordinate ferromagnesian individuals occur at times, all set in a dense lithoidal groundmass. The texture is so coarse at times and the porphyritic constituents so dominant that one might easily mistake the rocks for specimens of granite-porphyry.

Microscopical characters: The minerals present in *Specimen 261* from Mt. Gilmore comprise quartz, orthoclase, plagioclase, biotite, magnetite and apatite. The plagioclase is of the composition Ab_7An_3. The habit is tabular and the grainsize goes up to a maximum of .6 mm. in diameter. Decomposition is slight, with the development of kaolin, but albitization seems to be absent. The orthoclase is strongly kaolinized and the (001) cleavage is hard to discern. The individuals of quartz are large and equidimensional, showing a lot of corrosion and cracking. Biotite is almost completely resorbed with the production of strings of magnetite. Where unaltered, the mineral is of a pale green colour and feebly pleochroic. The magnetite is allotriomorphic and unaltered. Tiny crystals of apatite are seen as inclusions in the felspar and in the groundmass. The examination of the latter is difficult because kaolin and haematite have effected quite a lot of replacement. There is undoubtedly a little glassy residuum present, and the main part of the groundmass is cryptocrystalline. Spherulitic structures are absent. This rock is a biotite-dellenite. Elsewhere on Mt. Gilmore the unit becomes a toscanite on account of the plagioclase becoming $Ab_{11}An_9$ in composition and the orthoclase less abundant.

Specimen 391 from the Glenoak extension of the Mt. Gilmore type is a dellenite, in which the quartz is of smaller grainsize than is usual in these rocks, and possesses little in the way of corrosion effects. At Martin's Creek the horizon of the Mt. Gilmore flow is occupied by a toscanite which varies somewhat abruptly along the strike, becoming a dacite. The toscanite consists of basic andesine dominating over orthoclase and quartz, together with biotite and magnetite, all set in a cryptocrystalline groundmass, which has a little glassy base and shows kaolinization.

Paterson Type.

Megascopical characters: The rocks coming under this heading form a very distinctive unit which occurs throughout the whole of the area in a constant stratigraphical position. Since writing in 1922 the writer has not seen much to decide definitely the question of whether the occurrence of these rocks is as a composite sill or as a series of flows, but the microscopical evidence seems to strengthen the tentative view taken then that the latter case was the more likely. Thus, in some rocks, there appears to be a certain amount of tuffaceous material and some pumiceous structures.

In hand specimen the rocks are of a general grey colour where exposed to the atmosphere, but, when broken open, the colour of the comparatively fresh rock varies from brown to grey and blue. Phenocrysts of quartz, orthoclase, plagioclase and biotite are visible as in Specimens 69 and 71 from Hungry Hill, Paterson. At other times felspar is well shown, with quartz quite inconspicuous. The groundmass is always of felsitic appearance.

Microscopical characters: The minerals present comprise plagioclase, quartz, orthoclase, biotite, hornblende, magnetite and apatite. The quartz is generally present in large equidimensional crystals showing corrosion and inclusions of the groundmass. Orthoclase is sometimes fairly plentiful, at other times it becomes quite subordinate and the rock tends to become a dacite. The orthoclase is kaolinized and shows incipient albitization. Plagioclase exhibits a greater susceptibility to be replaced by albite, and along with the albitization is found the presence of chlorite replacing certain portions of the lime-soda felspar. The composition of the plagioclase varies from basic oligoclase to basic andesine. Biotite occurs in strips showing resorption, bending, bleaching and partial alteration to chlorite. The hornblende is quite fresh, although not at all abundant, and it is not of universal occurrence throughout the specimens. Its presence, however, is significant. Magnetite shows peripheral alteration to haematite, while apatite, which is only occasionally seen, is of acicular habit.

The groundmass is very dense and of a dark brown colour. The grainsize is cryptocrystalline in nature for the most part, although there are some patches of a glassy base. In two rocks from the south-west of Mt. Johnstone there are some pumiceous areas in the groundmass which have been devitrified, and this evidence points to these rocks having been extrusive.

Specimen 6, from the top of Mt. Johnstone, shows the presence of a little green hornblende as well as the other constant constituents. The plagioclase is of the composition Ab_3An_2 and the rock is a dellenite.

Specimen 7, from the railway cutting near Paterson Station, shows less phenocrystic quartz than is usual, and there is more albitization. The felspar is acid andesine and the rock a dellenite.

Specimen 70, from Hungry Hill, Paterson, is sandwiched in between two toscanites, *Nos. 69* and *71*. It is more felspathic in appearance than the type rocks, and the rock is almost an andesine-dacite allied to toscanite.

	I.	II.	III.	IV.	V.
SiO_2	73.04	72.98	74.60	72.79	68.36
Al_2O_3	13.86	12.58	13.41	13.77	13.24
Fe_2O_3	1.60	.28	1.28	1.69	1.29
FeO	.45	1.66	.30	n.d.	3.39
MgO	.48	.49	.26	.28	1.15
CaO	1.44	2.81	1.08	1.24	2.51
Na_2O	3.40	4.80	3.38	3.39	2.05
K_2O	4.39	2.99	4.50	4.38	5.34
H_2O+	.79	.79	.85	2.41	2.63
H_2O-	.25	.43	—	—	—
CO_2	absent	absent	—	—	—
TiO_2	.22	.40	.16	—	—
ZrO_2	absent	—	—	—	—
P_2O_5	.04	.08	.03	—	—
V_2O_5	absent	—	—	—	—
SO_3	absent	—	—	—	—
Cl	trace	—	—	—	—
S (FeS_2)	absent	—	—	—	—
F	—	—	—	—	—
Ni, Co. O	absent	—	—	—	—
CuO	absent	—	—	—	—
MnO	.07	.03	.06	—	.27
BaO	.04	—	.11	—	—
SrO	absent	—	absent	—	—
*Li_2O	present	—	trace	—	—
TOTAL	100.07	100.32	100.02	99.95	100.23
Specific Gravity	2.642	2.591	—	2.416	—

I. Dellenite, Mt. Gilmore, N.S.W. Analyst, W. A. Greig.
II. Dellenite, Paterson, N.S.W. Analyst, G. D. Osborne.
III. Rhyolite, California. Analyst, H. F. Hillebrand (Washington, 1917, p. 184).
IV. Obsidian, Hungary. Analyst, A. Logorio (Washington, 1917, p. 203).
V. Dellenite, Dellen, Sweden. Analyst, H. Santesson (Washington, 1917, p. 165).
* Spectroscopic.

Specimen 489, from the Porphyry Estate, Seaham, is a handsome blue rock with phenocrysts of quartz, orthoclase and plagioclase, and under the microscope is seen to be a toscanite. *Specimen 493*, from just south of Felspar Creek, is of interest in containing a little hornblende, and a slightly pumiceous groundmass. These features give it a great similarity to the rock from near Mt. Johnstone.

It is necessary to mention here that, while throughout the area one finds these toscanite and dellenite lavas comprising a group which is isolated from the main Volcanic Stage, still, just near Seaham, in two places, at Felspar Creek and Porphyry Point, respectively, small flows of rhyolite are to be found associated with the other rocks. In the Volcanic Stage, apart from the Mt. Gilmore toscanite-dellenite suite, there are two examples of tuffaceous dellenites in which there are some fragments of felsite and soda rhyolite. Autobrecciation, induced during the solidification of the rocks, is a rare feature, occurring in one instance only.

Chemical composition: An analysis of the Mt. Gilmore type of dellenite, which was kindly made for the author by Mr. W. A. Greig, is given above, together with one of the Paterson type of dellenite, *Specimen 7*, described above, which was carried out by the writer. In addition three analyses of similar rocks are tabulated.

As pointed out in the brief description above, *Specimen 7* shows albitization, the unaltered plagioclase being acid andesine. Calculated from the analysis, the lime-soda felspar is Ab_4An_1, so that the chemical evidence confirms the data derived from microscopical examination. In the case of the Mt. Gilmore rock it will be noted that the soda dominates over the lime, and this causes the calculated composition of the plagioclase to be about Ab_4An_1, practically the same as that determined for the Paterson rock. In both of these rocks there is an appreciable amount of potash, and this feature emphasizes the close relation these rocks have with the sodipotassic rhyolites. On account of the value for soda in the Paterson rock exceeding that of potash, the sub-rang to which it belongs is Lassenose, while the Mt. Gilmore rock fits in the sub-rang Toscanose.

Comparing the first four of the analyses tabulated, it will be seen that the two Kuttung rocks are quite similar in some respects, while the other two rocks, from California and Hungary respectively, show striking similarities to the Mt. Gilmore rock, especially as regards the values for the alkalis. The analysis, No. V, of the rock which was described originally as a hypersthene-andesite and later called a dellenite by Brögger, differs from the analyses of the Kuttung rocks particularly in having higher potash and lower silica, and indeed it is clear that the two Kuttung dellenites are very close to becoming sodi-potassic rhyolites.

Rhyolites.

The rhyolites are very abundant, especially in the Volcanic Stage, and present a variety as regards both chemical composition and texture. On account of the fact that many of these rocks are not strongly porphyritic, it is difficult, in the absence of many analyses, to classify them properly. It seems best, however, to consider them in two main sections, viz., those which contain soda felspar in abundance with the absence of visible orthoclase, and those which are sodi-potassic and in some cases strongly potassic.

Rhyolites characterized by Albite.

These varieties are quite distinct from alkaline lavas whose richness in soda is reflected in the composition of the ferro-magnesian minerals as well as the felspars, that is to say, the comendite-pantellerite suite. The sodic character of the rocks under consideration is due to the presence of albite, which might reasonably be regarded as of late-magmatic origin.

Megascopical characters: The rocks are light-coloured, and in the case of one important flow, almost emerald green. In the porphyritic varieties the constituents visible are dominant felspar, some quartz and often a little biotite. Frequently, however, there are practically no phenocrysts which can be determined megascopically. The texture of the groundmasses is always felsitic

Microscopical characters: The minerals present are quartz, plagioclase, biotite, magnetite, apatite, and rarely hornblende. Quartz may be quite abundant, while at times it is almost missing from the phenocrysts and occurs in the groundmass. It is generally corroded strongly and shows inclusions of the groundmass. The plagioclase is almost always albite, but in one slide some oligoclase was seen. In this case it was being replaced by albite and, indeed, it is probable that much of the phenocrystic albite in the rhyolites is not of primary crystallization, as it exhibits many of the features of the albite in albitized rocks. The felspar is well formed in most cases and possesses a stout prismatic habit. Biotite is present in variable amount, absent in certain rocks, and it is generally strongly resorbed. The pleochroism is always weak. Hornblende was not observed to be a regular constituent, but its presence was detected in a rock from near the top of Mt. Gilmore. The iron ore is mostly ilmenite, but both ilmenite and magnetite occur, the latter being slightly haematitized. Apatite is found in minute quantities in the majority of the rocks.

The textures exhibited by these sodic rocks are interesting. Cryptocrystalline groundmasses are the rule and these may be so fine that little can be done in the way of resolving them. Where slightly coarser, one can detect the presence of quartz and acid plagioclase. Spherulitic structures are not common, being generally seen in those rocks which show the presence of secondary quartz. The presence of much pumiceous material, considerably altered, is however a distinctive feature. Thus there may be patches of material which consists of remnants of bubbles which have been re-welded, giving the bogen-structur of Mügge (1893). Secondary silicification has in most cases filled the interstices between some of the disrupted bubbles, while devitrification, followed by kaolinization, has brought about a selective replacement of the material composing the pumice remnants. Flow structure is to be found in the rocks which are not pumiceous and sometimes spherulites are found in the lines of flow, apparently having developed after the congealing of the material exhibiting the flow lines.

The most important occurrence of the soda rhyolites is to the west of Martin's Creek near the road at the foot of Mt. Johnstone. *Specimen 258*, from here, is a green rock with an even fracture, and is studded with tabular idiomorphic white felspars. Under the microscope some phenocrysts of corroded quartz are seen, but the felspar is much more abundant, having a spongy appearance suggestive of having developed by deposition during replacement. The grainsize of the felspar is fairly even, and averages about .6 mm. The groundmass is pumiceous and contains some tiny fragments of quartz and rock material. There has been some devitrification and kaolinization. The rock is best called a tuffaceous soda rhyolite. It is almost identical with some specimens from a Kuttung flow at Currabubula, the petrographical features of which have been given by W. R. Browne (1920, p. 408).

While the soda rhyolites are being considered it can be pointed out that there are some flow breccias, e.g., *Specimen 375*, occurring in the Langlands section and elsewhere, which are very sodic and present structures which have developed as a result of autobrecciation during the cooling of an acidic alkaline magma.

Rhyolites in which Orthoclase is an Important Constituent.

These varieties are of more frequent occurrence than the sodic rocks. Using the criterion of the nature of the phenocrysts one can distinguish between sodi-potassic and those which are dominantly potassic, but it is to be remembered that in all cases it is likely that both the soda and potash molecules exist in the material of the groundmass so that the distinction is one of expediency only, and to be used in the absence of analyses.

Megascopical characters: The rocks vary a great deal as regards colour, being often of a dark brown and other times light-coloured. The fracture is quite irregular in those containing large phenocrysts and even in the felsitic types. Quartz is conspicuous in certain specimens and almost absent from others, while the two varieties of felspar are generally distinguishable in hand specimen.

Microscopical characters: Under the microscope the following minerals are present: quartz, orthoclase, plagioclase, biotite, ilmenite, apatite and magnetite. The quartz is always corroded and sometimes considerably cracked, though there are no strain shadows under crossed nicols. The orthoclase may be very dominant in those rocks which are taken as being strongly potassic, while it equals, roughly, the amount of plagioclase in the sodi-potassic varieties. The potash felspar is tabular in habit, is always kaolinized, and invariably shows the (001) cleavage. A little albitization is to be seen in several instances. The plagioclase is generally idiomorphic, and of a tabular prismatic habit. The composition varies from albite to medium oligoclase. Biotite shows a slender habit and generally is strongly resorbed. Ilmenite, indicated by a titaniferous decomposition product, is of more frequent occurrence than magnetite, and apatite is fairly constant in minute prisms.

The groundmass of the rocks is mostly cryptocrystalline and residual glass is not a constant feature, although there is some in certain rocks. Flow structure occurs in one or two cases, but it is the presence of pumiceous patches which forms the commonest feature. There has always been devitrification of this pumiceous glass and sometimes secondary silica has entered and affected these pumiceous areas.

There are many of the sodi-potassic rhyolites in the Mt. Gilmore section as, for example, *Specimens 354, 168, 198, 200* and *497*. Of these *168* is distinctive on account of its reddish colour, and amygdaloidal appearance. The colour is due to the selective replacement, by haematite, of a pumiceous groundmass.

Specimen 497 is of some interest in being the matrix of a volcanic conglomerate at the top of the Mt. Gilmore section. It possesses abundant phenocrysts of quartz with subordinate orthoclase and biotite set in a cryptocrystalline groundmass. Associated with the toscanite of the Paterson type, there occur at Porphyry Point and Felspar Creek, Seaham, varieties of potash rhyolite, e.g., *Specimen 486*, which conform to the general description given above.

Felsites.

In addition to the rocks already described there are quite a number which are non-porphyritic and of a typical felsitic appearance. They are generally light in colour, although some dark brown types are known. Under the microscope one is unable to assign any definite identity to these rocks since phenocrysts are extremely rare and when present are generally of quartz or, if of felspar, are too small or too altered to admit of accurate determination. The groundmass in these rocks, which in places constitutes almost 95% of the whole, may be cryptocrystalline as in the case of *Specimen 374*, from Oakendale, or it may be an altered pumice as in *Specimen 17*, from near the Gostwyck Bridge, Paterson. In this rock the attenuated bubbles have been replaced by kaolin and filled with secondary silica.

In the case of a group of felsitic rocks occurring to the east of the Railway on the southern side of the valley of Martin's Creek (*Specimens 25* and *26*), the groundmass contains many spherulites and axiolites as already described (see above).

In connection with the felsites one can point out that although the phenocrystic felspar was very scarce and always somewhat decomposed, measurements that were made upon the extinction angles suggested that in all cases the felspars were strongly sodic, although the determination was never definite.

Tuffs and Certain Detrital Rocks.

Tuffs.

A salient feature of the Kuttung Series is the abundance of tuff throughout. Much of this tuffaceous material is mixed with detrital sediment and it is impossible to arrive at the composition of the material of truly igneous origin in these cases. There are, however, some tuffs which appear to be of primary deposition and therefore of importance almost equal to that of many flows. These tuffs do not vary much in hand specimen, being generally of a rusty red colour, due to the presence of haematite. At other times the tuffs are greenish, due to the presence of a silicate of iron. The grainsize is generally even and medium, cases of coarse breccia and agglomerate being relatively rare.

Microscopical characters: Microscopically there are seen to be certain differences in the various specimens and the leading types will be considered in turn.

Specimen 147 is from the Mt. Gilmore section and contains fragments of acidic rocks, some of which are felsitic and some of the nature of keratophyres. Albite occurs along with quartz. Some patches of secondary silica are seen and haematite is the cementing material. It is interesting to notice again the prevalence of sodic constituents.

Specimen 10, from the little quarry on the Paterson-Dungog road near Mt. Johnstone, contains fragments of quartz and andesine together with a lot of pumice cemented by a greenish matrix. The pumice has been replaced in part by haematite and shows up well in contrast to the rest of the rock. Secondary silica occurs in patches and there are some vitrophyric rock inclusions.

Specimen 294 which is dark in colour is from the Tillimby paddock, Paterson. It is very finely textured and consists of quartz and indeterminate felspar set in a dark brown matrix. High magnification shows this to consist of tiny pieces of siliceous rock, haematite and chloritic (?) material.

Specimen 298, from about three-quarters of a mile south of Martin's Creek Station and east of the Railway Line, is of interest in that there is a considerable amount of biotite present.

Specimens 373, 381, 383 and *449* are tuffs occurring in the Langlands section and are all of the same general facies, being siliceous, the fragments comprising abundant quartz, acidic rocks (many of which are quite glassy), spherulites, and chips of acid plagioclase.

It will thus be noticed that nearly all the tuffs have constituents which give the rocks alkaline affinities and that in some cases biotite is an important constituent.

Tuffaceous Rocks in the Main Glacial Beds.

The lithology and petrography of the Main Glacial Beds have already been written (Osborne, 1925) and it has been pointed out there that many rocks which would be taken at first sight to be tuffs or breccias are, in part at least, of glacial origin. As a matter of fact there are only local masses of true tuff and breccia, but extensive deposits of tuffaceous sandstones and coarser rocks occur.

With regard to the composition of the few true tuffs, microscopical examination has shown the fairly constant features of a siliceous character and a content of acid plagioclase.

Basal Stage Conglomerates.

Conglomerates form such an important part of the Basal Stage in the vicinity of Wallarobba, Mt. Douglas and Clarencetown, and it is desirable that a petrological description of these be given.

The pebbles in the conglomerates average about 4 inches in diameter, while some are about one foot in diameter. The nature of these old gravels has not been determined in any detail, but the pebbles occur in the following general order of decreasing abundance: quartzites, aplites, cherts, porphyries, felsitic rocks and granitic types. There is an almost entire absence of rocks belonging to the diorite-andesite suite. The nature of the matrix of the conglomerates no doubt varies from place to place. Some samples show, in hand specimen, the presence of fairly fresh chips of felspar along with quartz and tiny rock fragments. A fairly representative sample is *Specimen 152* from Clarencetown, near the Williams River Bridge. Megascopically it is of a dark grey colour, the constituents being of a fine grainsize cemented by argillaceous material.

Microscopically, it is seen to be composed of fragments of siliceous rocks, quartz, and plagioclase, with patches of chlorite and haematite, the cement being kaolinic. Many of the rock pieces are devitrified obsidians possessing spherulites. Other rock types are felsitic and may always have been lithoidal. There is evidence that the fragments have been somewhat rounded by transport.

Petrography of Certain Post-Carboniferous Rocks.

As pointed out in another paper, there occur in the area under discussion remnants of widespread flows of Cainozoic basalt and several dykes of basic material. The material of the dykes is in all cases too much weathered to permit microscopical examination, with one exception, this being the dyke on Mr. A. J. C. Vogele's property at Mt. Douglas.

Specimen 82, from the margin of the dyke, is of finer grainsize than *Specimen 106* which is from the central portion of the mass. Both are somewhat porphyritic in plagioclase and show a typical doleritic appearance.

Microscopical characters: *Specimen 82* is seen to be a good deal decomposed. There are present plagioclase, augite, magnetite, biotite, apatite and a little free quartz. The plagioclase occurs as phenocrysts at times, but the bulk of it belongs to the second generation, having a prismatic habit. It is very much saussuritized and its composition is almost indeterminate, although there is no doubt of it being calcic. Augite is grey and ophitic relations exist between it and felspar. There is very little biotite which, like the magnetite, is fresh. Chlorite and haematite are seen to be filling cracks rather than representing replacement patches due to decomposition. In addition there is a considerable quantity of a secondary greenish silicate. The quartz is interstitial and undoubtedly was the last mineral to crystallize.

Specimen 106 is coarser in grainsize and there is a fair amount of phenocrystic plagioclase which possesses a tabular habit and an average grainsize of 2 mm. The composition of the phenocrysts is about Ab_2An_3, while that of the felspar in the groundmass is slightly more acid. The latter is prismatic in habit and is associated with quartz, augite, titaniferous iron ore, biotite, quartz and apatite, the mass showing ophitic fabric. Chlorite is the chief decomposition product.

Both the above rocks may have the name quartz-bearing gabbro porphyrite or porphyritic dolerite.

Specimen 85 is from the basalt on Mt. Douglas. In hand specimen it has the normal basaltic appearance, and under the microscope is seen to be an olivine-basalt. The olivine phenocrysts are completely pseudomorphed by the material which is generally described as iddingsite, and limonitic stains which have originated from the alteration of the olivine show also that this mineral was originally distinctly ferriferous.

In the groundmass, which is subophitic in texture, there are laths of basic plagioclase, considerable iron ore, augite and apatite, all remarkably fresh in contrast with the olivine. A significant feature in connection with the order of consolidation is that the bulk of the iron ore crystallized in ragged masses after the felspar.

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EXPLANATION OF PLATE XXIII.

Fig. 1.—Example of albitization of a phenocryst of andesine in a rhyolite from Mt. Gilmore. The remnants of andesine are white and stand out in contrast with the rest of the grain which is now albite. Ordinary light. Magnification, 28 diameters.

Fig. 2.—Composite zoned crystal of plagioclase in the Martin's Creek andesite showing selective replacement by albite and chlorite. The latter has replaced some of the central zones, while the former is found towards the periphery, and is separated from the chlorite by a zone of unaltered andesine (white). Crossed nicols. Magnification, 12 diameters.

Fig. 3.—Williams River type of quartz-keratophyre. Clear grains of quartz and subidiomorphic grains of spongy albite are set in a dense groundmass. Polarized light. Magnification, 12 diameters.

Fig. 4.—Lithoidal phase of pyroxene-andesite showing the presence of augite (oval grain near centre) and prismatic hypersthene. Polarized Light. Magnification, 12 diameters.

Fig. 5.—Glassy variety of transitional type of andesite. Portion of a resorbed phenocryst of hornblende is to be seen towards the top, while augite and hypersthene are in association as indicated, and small pieces of biotite occur scattered near the centre. Ordinary light. Magnification, 14 diameters.